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Modeling Nitrogen Transport in the Newport Bay/San Diego Creek Watershed

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in

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by

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ABSTRACT

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Master of Science, Graduate Program in Environmental Sciences
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The Newport Bay/San Diego Creek Watershed has had a total maximum daily load (TMDL) established for the allowable loading of nitrogen into the bay. Although agriculture is identified in the TMDL as a major contributor of nitrogen in the watershed, observations from a monitoring study and estimates from a conceptual model show that agriculture is contributing far less than assumed. As a result, limitations on loading from agricultural sources to be obtained by 2007 have already been met. Agricultural land use in the region has been greatly reduced, from approximately 20% of the watershed area in the 1980s to a current 2% of land area. A simple nitrogen transport model predicts that agriculture now contributes only 2% of total N loading directly to surface waters. An additional 6% from agriculture is contributed if estimates of leaching to shallow groundwater and subsequent mixing with surface water are also considered. The time lag involved in groundwater mixing suggests that even if all remaining agricultural production in the watershed were ceased today, the effects of nitrate loading from fertilization would continue to be seen for another 10 to 30 years. The greatest input to

current surface water conditions is not agriculture, but increasing urban development. Nurseries also contribute a significant portion of nitrate, and have the highest contribution per unit area of any N source.

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Introduction

Excess nutrient loading to Newport Bay over the past few decades has contributed to seasonal algal blooms resulting in both San Diego Creek and Newport Bay being added to California's 303(d) list for water bodies of impaired quality in 1996. In 1998, the Santa Ana Regional Water Quality Control Board adopted a total maximum daily load (TMDL) for nutrients in the watershed. The baseline estimate for annual average total nitrogen, as compiled from 1990 – 1997, is 493,063 kilograms for the watershed as a whole. Just under one third of that total, 148,800 kg/year, is allocated to agricultural discharges, 65,900 kg/year for wasteload allocations from three permitted nurseries, and the remainder from urban runoff and undefined sources including rising groundwater and atmospheric deposition (Table 1).

The ultimate goal outlined by the TMDL is to reduce the annual load and concentration of total nitrogen and phosphorus to Newport Bay by 50% by 2012, with the first load reduction goal set for the summer season (April – September) 2002. By this time, the non-point source agricultural discharge of total nitrogen is to be limited to 10,416 kg/season. Winter season (October – March) allocations are not set until 2012.

	Baseline Loading, 1990-97 (kg/yr)	2002 Summer Target (kg/season)	2007 Summer Target (kg/season)	2012 Winter Target (kg/season)
Nursery	65,894	30,547	28,389	10,460
Agriculture	148,800	10,416	5,208	17,365
Urban Runoff	125,707	9,428	7,542	25,148
Undefined Sources	No Baseline	28,728	17,008	6,323
Watershed Total	493,063	90,764	69,791	65,484

Table 1. Seasonal total nitrogen load allocations for the Newport Bay Watershed. Modified from Table 5-9b of SARWQCB, Resolution 98-100.

The load restrictions are intended to facilitate attainment of water quality objectives for Reach 1 of San Diego Creek (Jeffrey Road to Newport Bay) of 13 mg/L total inorganic nitrogen (TIN) and 5 mg/L TIN for Reach 2 (Jeffrey Road to headwater).

This thesis uses results from field observations and modeling studies in the watershed to answer the following questions:

- What are the current nitrogen loads to surface water contributed by strawberry crops, as representative of agricultural discharges throughout the watershed?
- What is the load contribution to shallow groundwater from agricultural sources?
- What is the hydrologic lag time from the field surface to groundwater and out to surface water?
- How will changes in management of different N sources (agriculture, nurseries, urban) affect future nitrogen concentrations in San Diego Creek?

Methods

Site Description

The Newport Bay/San Diego Creek Watershed covers 400 square kilometers in the center of Orange County, California. The upper watershed covers 287 square kilometers, containing San Diego Creek and its tributaries. San Diego Creek is the primary freshwater input to Upper Newport Bay, and is also the repository for agricultural and urban drainage throughout the watershed. In the early 1980s, roughly 30%, or 8,500 hectares (Tetra Tech, 2000), of the upper watershed was characterized by agriculture, primarily citrus orchards. Urbanization over the last couple of decades has dramatically reduced agricultural land use in the area. By the year 2000, orchards of citrus and avocado were reduced to 810 ha, while row crops comprised another 1,620 ha of agricultural land (Wu and Kabashima, 2001). The next year saw another drop in agricultural area to approximately 526 ha in orchard production and 728 ha of row crops in 2001 (Orange County PFRD, 2001). The primary row crop grown within the watershed is strawberry, covering 431 ha in 2001. Tomatoes are second in area with 166, while miscellaneous crops, including beans and peppers, make up the remainder.

The University of California South Coast Research and Extension Center in Irvine (SCREC) established an agricultural monitoring program in December 1999, in part to quantify nutrient flows from agricultural fields. Four strawberry crop sites in the watershed were set up to be monitored for discharge flows and nutrient concentrations. Each crop site consists of two similar fields ranging in size from approximately 1.3 to 13 ha (Table 2) with monitoring at each field. Water sampling and flow measurement equipment were installed at each plot and samples taken beginning in April 2000.

Site	Station	Size (ha)
A	R-1	1.73
	R-2	2.04
B	R-3	3.22
	R-4	3.41
C	R-5	1.35
	R-6	1.35
D	R-7	11.84
	R-8	13.00

Table 2. Site Identification

The strawberry crop cycle in the Newport Bay watershed can be broken into three general stages: (1) *Planting/ Establishment,* beginning in late-September and typically ending in mid- to late-October; (2) *Growing,* from November through December; and (3)

Harvest, beginning in January and continuing through June. The fields are not used for crop production during the months of July and August. During the planting/ establishment period, fields are irrigated by overhead sprinklers. After establishment of the strawberry transplants, drip irrigation replaces the sprinklers for the remainder of the crop cycle.

The timelines for the nutrient TMDL are broken into two seasons, which overlap the strawberry crop cycle stages. A summer/dry period, April through September, includes the latter part of the harvest phase as well as the first portion of the establishment phase; while a winter/wet period, October through March, includes all or part of each phase.

The TMDL season breakdown follows the natural rainfall pattern within the watershed. With climate data gathered by the Western Regional Climate Center for Tustin Irvine Ranch, averages over the past 70 years show that the months of greatest rainfall are November through March, with regular storms still occurring into the beginning of the summer season in April. May through October are generally very dry (Table 3).

In addition to regular intra-annual variability, the region is known to experience extreme variability in inter-annual precipitation. Although the average annual precipitation is approximately thirty-three centimeters, years of drought in which

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. ppt. (cm.)	6.50	6.91	5.61	2.57	0.66	0.18	0.03	0.20	0.71	0.91	3.30	5.03

Table 3. 73-year, monthly average precipitation at Tustin Ranch, within the Newport Bay watershed.

the region can receive as little as ten to twenty cm of rain can be followed by very wet years in which rainfall can accumulate up to seventy cm (Figure 1).

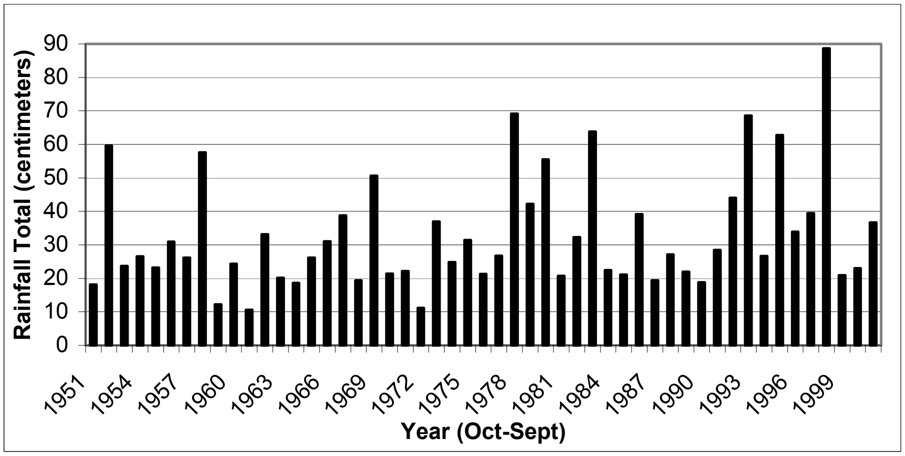

Figure 1. Annual precipitation at Tustin Ranch for water years 1951-2001.

Equipment and Procedures

Area-velocity flow meters (American Sigma, 1998) were located at each site in a manner such that surface runoff was measured continuously. Automatic water samplers (American Sigma, 1998) were placed in the field to sample surface runoff for a 24-hour period once a week. These samples were then analyzed for the following water quality parameters: pH, $(NO_2 + NO_3)$-N, NH_3-N, TKN, PO_4-P and total-P. Nutrient analyses were conducted by Irvine Ranch Water District's EPA-approved water testing laboratory.

To calculate the loading of total nitrogen exported from the fields, the concentrations of $(NO_2 + NO_3)$-N, NH_3-N, and TKN, all in mg/L, were each multiplied by the average flow rate (in units of L/hr) at the time of the sample, the sample time interval, and then converted from milligrams to kilograms. The individual components were then summed to give total nitrogen (TN) in kg (equation 1).

$$X \text{ mg/L} * Y \text{ L/hr} * Z \text{ hr} * 1.0\text{x}10^{-6} \text{ kg/mg} = 1.0\text{x}10^{-6} XYZ \text{ kg} \tag{1}$$

While flow volume measurements were continuous, practical limitations on sampling frequency require extrapolation of data from discrete water samples collected to monthly, seasonal or annual totals. Monthly volume-weighted means were obtained by averaging the concentration measurements of a given month, multiplying that average by the total flow volume for the month, then converting units to yield an average load in kg per month. This average was then compared to the actual measured loading rate during the sampling days and the greater of the two values was used as the final average of total nitrogen per month. The total was then divided by the area of the field in order to obtain a standard loading per hectare.

Seasonal or annual loading averages were computed by first averaging the desired per hectare monthly averages (for example, October through March for a wet season average) of a given field and then averaging all fields together. Monthly loading and concentration averages from each site and of all sites combined were plotted against discharge and a linear correlation analysis was conducted.

Field Nitrogen Mass Balance

Nitrogen leaching by drainage from strawberry fields was calculated by mass balance, starting with published values of fertilization and irrigation needs (UC IPM, 1994). Additional nitrogen added to the system through irrigation water was calculated from the reported average nitrate-nitrogen content at IRWD's Michelson Water

Reclamation Plant (IRWD, 2001). Losses of fertilizer from N_2O emissions and plant uptake were also considered. Growers in the watershed typically use controlled-release fertilizers (CRF), which have been effective in reducing loss of applied fertilizer N to NO_3^- leaching as well as N_2O loss from denitrification (Shoji et al., 2001; Wang and Alva, 1996). Field experiments using CRF on barley and corn fields found respective N_2O-N emissions to be 0.24 and 0.59% of applied fertilizer N (Shoji et al., 2001). Although not expected to be a significant loss, an estimated 0.45% of applied N was used to account for nitrogen loss from the system through N_2O emissions.

The 2001 Orange County Crop Report provided the weight of strawberries produced within the county at 41,232 metric tons. Assuming 90% of the strawberries produced in the county are produced within the San Diego Creek watershed (SCREC, personal communication, 2002), the production value for the watershed was obtained. While 90-94% of the fruit weight can be allocated to water (Albregts and Howard, 1978; Bogert et al, 1973; Bowes1994), published values for the nitrogen content of strawberries were found to range from 0.096 to 0.134% of fresh fruit weight with an average of 0.113% (Albregts and Howard, 1978). By multiplying the production weight by the average nitrogen content, the total fruit N content is calculated. Other published reports show that the total amount of fertilizer N recovered in fruit is approximately equal to that in vegetative tissues (Archbold and MacKown, 1988; Langford, 1996). Thus the total N removed by the crop was assumed to be twice the fruit N content. A mass balance equation starting with nitrogen applied (through both fertilization (F) and irrigation (I)) and subtracting that released as N_2O (NR), removed by plant/fruit material (PM), and measured in runoff (R), yielded leaching values for the strawberry crops that varied according to fertilization regime used (equations 2 & 3).

$$\text{N leached (kg)} = (\text{Ha planted} * \text{N (F + I) kg/ha}) - \text{NR} - \text{PM} - \text{R} \qquad \textbf{(2)}$$

$$\text{\% leached} = \text{N leached (kg)} / (\text{Ha planted} * \text{N (F + I) kg/ha}) \qquad \textbf{(3)}$$

Groundwater Estimations

Depth to groundwater analysis was done with use of GIS. Map layers of ground elevation and groundwater elevation were obtained from USGS and the Orange County Water District, respectively. The groundwater elevation contour map was converted to a triangulated irregular network (TIN) to provide an estimated area view of the map. The TIN was then converted to a grid of equal cell size to the USGS ground elevation map. A new map layer was then created by subtracting groundwater elevation from ground elevation to give a depth to groundwater.

A GIS soil map provided by the County of Orange, based on the 1978 USDA soil survey of Orange and Western part of Riverside Counties, overlaid by a map layer of current agricultural area in the watershed, identifies the majority of soils in that area as belonging to hydrologic soil group B, silt loam or loam soils. Assuming the soils are at field capacity, soil water content was estimated to be 0.25. A leaching fraction of water was assumed to be between 15 and 25% of the required irrigation. The lower end of 15% is estimated to account for relatively low salinity in the area, and thus a decreased need to leach salts from the root zone. The upper end of 25% represents the potential inefficiency of the system by which growers purchase water in advance and will tend to use all the water purchased regardless of actual need.

In addition to excess irrigation water used for leaching, storm water also contributes to the total downward flow volume. All rainfall to agricultural fields was assumed either to run off, or contribute to leaching. A precipitation summary for Tustin-Irvine Ranch, Station 61, for the 2000-2001 rain year (July – June) provided daily precipitation totals throughout the year (OC PFRD, 2001a). To obtain the precipitation volume on each field site, the area of each field was multiplied by the daily precipitation total. Monitoring reports from each field provided daily runoff volumes that were then subtracted from the precipitation volume, yielding the estimated storm water contribution to leaching. The average contribution from the eight fields was normalized to the average annual rainfall and added to the irrigation leaching volume.

The length of time for nitrate leached from the soil to reach groundwater was calculated by equation 4, where D is the depth to groundwater in meters, θ is the volumetric water content, and L is the leaching fraction (irrigation plus precipitation) in meters per year:

$$\text{Time} = D \times \theta / L \tag{4}$$

Equation 5 calculates the average concentration of the nitrogen that would reach groundwater, assuming complete mixing of the N and drainage volumes below a field. In this equation, FL is the mass of fertilizer per ha leached past the root zone and V is the per ha volume of water leached in liters.

$$[N] = FL/V \tag{5}$$

Conceptual Model

A conceptual mass balance model of nitrate loading from urban and agricultural sources to San Diego Creek was used to illustrate the effect of a management change over time. The model uses a piston flow approach through parallel 'stream tubes' to reflect differences in travel time from various sources, including those that contribute directly to surface water versus sources whose contributions must first travel through groundwater. Data inputs to the model from the County of Orange regional monitoring program and three detailed nutrient studies are used to break down the nitrate loading and streamflow into separate areas of contribution. More specific data from the previously outlined agricultural monitoring program, waste discharge reports from three major nurseries, and preliminary results from an Irvine Ranch Water District residential study were also used to characterize contributions from different sources.

The watershed is drained by San Diego Creek, of total length L, whose flow volume is derived from return flow of agricultural, nursery, and urban areas as well as upwelling from shallow groundwater. Monitoring in San Diego Creek at Campus Drive (SDMF05), which is the last main-stem monitoring point before water enters Upper Newport Bay, provides an estimate of the sum of the flow from each source. Similarly, each source of nitrate is assumed to be connected to the creek by a stream tube carrying it to the final monitoring station. At the beginning of each tube, whether from the edge of the nursery or at a monitoring station upstream of SDMF05, the NO_3-N input concentration (Co_J) is assumed to be constant and equal to the flow-weighted mean concentration discharged from that point. Uptake or loss of NO_3-N from the system is not considered. Using parallel stream tubes, the contribution by a source, J, to the nitrate mass flow rate (Q_{SJ}) arriving at the end of the creek at time t is represented by the following:

$$Q_{SJ}(t) = Q_J * H(t-t_J) \tag{6}$$

where Q_J is the flow contribution from the J^{th} source, t_J is the travel time to the creek from the J^{th} source, and $H(t-t_J) = 0$ if $t < t_J$, and $=1$ if $t > t_J$. Thus, each source 'switches on' at the creek after it has traveled the distance from the source. Assumptions made to derive this function are as follows:

- The travel time is the sum of the time to travel from the source to the river, t_1, and the time to travel from the point of entry at the river to the end of the river (or final monitoring point), t_2. In practice, $t_2 << t_1$, and can be neglected for most model applications.
- The travel times are uncorrelated.
- Mixing between tubes is neglected until averaged at the end of the river.

For the agriculture and nursery sites, contribution to shallow groundwater was considered along with surface flow. For these inputs to the model, in addition to the previous assumptions, travel time to groundwater is assumed to be by piston flow as is travel within groundwater. Travel time from the source to the river, represented by t_1 in the surface flow section, is now the sum of downward travel time in the unsaturated zone, tu_J, and lateral travel through the groundwater to a point where groundwater mixes with surface water, tg_J. Travel time through the unsaturated zone is dependent upon the depth of the zone, D_J, average water content, θ_J, cross sectional area, A_J, and flow volume, Q_J and was derived by the methods described in the previous section. Travel time within groundwater is a function of the distance of travel, Y_J, and velocity, V_G. Travel time within the river, previously represented by t_2, then becomes a function of distance from the point of mixing with surface water, X_J, to the end of the river, L - X_J, traveled at a velocity V_R. These travel times can be summarized by the following:

- Unsaturated zone time, $tu_J = D_J * \theta_J * A_J / Q_J$
- Groundwater zone time, $tg_J = Y_J / V_G$
- River travel time, $tr_J = (L - X_J) / V_R$

In this simplified scenario, the concentration of nitrate arriving through any stream tube at the end of the river becomes

$$C_J(t) = C_{OJ} * H(t - tu_J - tg_J - tr_J) \tag{7}$$

The mean concentration of all inputs is then,

$$C_T(t) = \frac{\sum_{J=1}^{N} Q_J * C_{OJ} * H(t - tu_J - tg_J - tr_J)}{\sum_{J=1}^{N} Q_J} \tag{8}$$

Model Parameterization

The direction of groundwater flow, determined through GIS functions using the groundwater elevation map, was used to determine the distance from the point of origin to the point of upwelling. The Orange County Water District provided an estimate of 4.5 meters per day for the flow velocity of the shallow groundwater (OCWD, personal communication, 2002).

Because travel time through the groundwater system is orders of magnitude longer than travel time through surface water (decades versus hours to days), all surface travel times are given a value of 0.01 years regardless of distance from the monitoring point. The initial condition of the outlet (the river) is set equal to the steady state condition from all inputs. Thus, a change in management to a sector of the watershed will be reflected in the length of time it takes to reach a new steady state condition as a result of that change.

To distinguish different areas within the watershed, fifteen sub-watersheds were delineated based on contributing areas to sampling sites used by Orange County in their intensive nutrient studies of September 1999, June 2000, and May 2001, as summarized in the May 2001 report (Table 4). A more detailed sub-basin delineation developed by Boyle in 1982 and reproduced in a 2000 watershed report (Tetra Tech, 2000) was used as a rough guideline. The agriculture, nursery, and residential areas identified in the monitoring program and IRWD study lie within specific sub-watersheds. The sites, as

Monitoring Site Location	**Site Reference Code**	**Monitoring Site Location**	**Site Reference Code**
Peters Canyon Wash u/s Hicks Canyon Wash	USHF06	San Diego Creek at Harvard Avenue	WYLSED
Hicks Canyon Wash	HCWF27	Barranca Channel	BRCF09
Central Irvine Channel	CICF25	Lane Channel	LANF08
El Modena-Irvine Channel	MIRF07	San Joaquin Channel	SJQF14
Como Storm Channel	CSCS03	Sand Canyon Channel	SCCF15
Santa Ana-Santa Fe Channel	SAFF10	San Diego Creek at Campus Drive	SDMF05
Valencia Storm Drain	VALS02	Lyon Storm Drain	F06S07
Peters Canyon Wash at Barranca Parkway	BARSED		

Table 4. County monitoring sites used.

well as remaining areas in all sub-watersheds were characterized by one of four land use types: agriculture, nursery, urban, or open space. Land use was determined by a combination of a January 1999 map used in the Tetra Tech report, as well as a February 2001 land use map developed and produced by the County of Orange.

Annual flow volumes for four monitoring sites, MIRF07, WYLSED, BARSED, and SDMF05, were taken from the 2001 report of the regional monitoring program (Orange County et al., 2001), which covers the period of July 1, 2000 through June 30, 2001. Flow for the other eleven sites was determined using data from three county nutrient monitoring studies. The three discharge volumes were averaged, extrapolated to an annual flow, and multiplied by a correction factor of 2.5 to account for increased winter flows not captured in the three summer season studies. The sum of all calculated or reported contributing flows measured 96% of measured flow at BARSED, and 99% at SDMF05.

Surface flow from the three nursery sites represents the sum of individual month discharges for the 2001 calendar year. Flow from the agriculture areas was determined by summing the monthly flows from each site for the 2001 calendar year and dividing by the area of that site. The resulting annual flow per ha values were then averaged to give a general agriculture surface flow of 1040 $m^3\ ha^{-1}\ yr^{-1}$. Multiplying this by the area of the agriculture sections used in the model yielded the surface flow contribution of those sections.

Nitrate-N concentrations for six sites were obtained from the county monitoring report (specifically the same four with flow data, plus CICF25 and LANF08).

Concentrations for the other nine sites were estimated by taking the flow weighted average of the three nutrient study measurements. The annual average concentration from each of the nursery sites was determined by calculating the flow-weighted average of monthly concentrations as reported in their discharge reports filed with the Santa Ana Regional Water Quality Control Board. The nitrate-N concentration used for the agricultural sites was derived by taking the flow-weighted average of all samples for a particular site during 2001, then weighting those averages by the area of each site over the total sampled area to yield the 'average agricultural NO_3-N concentration.'

With inputs of concentration, time of flow through the subsurface, time of surface flow, percent of total flow, and land use type, the model was run to create a picture of the impact of management changes, and the time scale on which that impact would be seen.

Results

Estimated Surface Loading from Agriculture

Initial monitoring, from April 2000 through October 2001, revealed that the highest levels of surface runoff from the row crop fields could be attributed to either storm events, or the establishment phase. Storm events, however, are specifically excluded from TMDL allocation when they occur in the winter season and result in a flow rate at SDMF05 of greater than 1.415 cubic meters per second. Establishment of strawberry transplants results in high levels of surface runoff due to frequent use of overhead sprinkler irrigation. Once the plants are established, irrigation practices shift from sprinkler to drip, resulting in negligible irrigation runoff from the fields for the remainder of the crop cycle.

With an average 33 cm annual precipitation, rainfall is an important factor in the transport of nitrogen from agricultural fields to the bay. Rain events not only increase runoff from the fields and loading of nitrogen to surface waters, but also contribute to leaching of nitrogen within the soils down to groundwater.

The years of field monitoring by SCREC have been average to dry years. This past 2001-2002 winter season was particularly dry with a county average of only 14.83 centimeters of rain. In this dry year, an average of almost six kg/ha were calculated as the average of each site's loading during the winter season (Table 5). This average includes loading as a result of storm events that would not be counted toward TMDL compliance. The previous average rainfall year (37.01 cm) yielded a winter average of 18 kg/ha, also including storm discharges.

Loading, kg/ha	2000-01	2001-02
Average	18.03	5.79
Std. deviation	14.92	2.53
Coeff. of variation	0.83	0.44

Table 5. Average winter loading from all sites of total N

Summer season data is less available, but conservative estimates show that even with normal April rains, loading would fall at three kg/ha or less for the season. Extrapolating these estimates over the total 1620 ha of row crop area (year 2000) yields a winter loading of 9,000 to 29,000 kg for the winter season, depending largely on rainfall, and 5,400 kg for the summer season. The lower winter loading from 2001-02 is well under the 2012 TMDL winter target of 17,365 kg per season; while it is possible the

2000-01 would also be if storm events were discounted. The summer estimate falls well within the 2002 summer target of 10,416 kg and just slightly above the 2007 target of 5,208 kg. However, when totals are adjusted further for decreasing crop area, the loading falls below the summer target for both 2002 and 2007.

While it may be tempting to speculate that concentration of nitrogen in tail water would be inversely proportional to discharge, whether a result of irrigation or storm event, such a speculation is not supported by the data. When each field is analyzed separately, R^2 correlation values for the relationship range from 0.0002 to 0.1905 (data not presented). When data from all sites are combined, the overall R^2 is 0.0125, showing no linear relationship between the two parameters (figure 2a).

A better argument can be made for the relationship between loading and discharge with five of eight fields yielding R^2 values greater than 0.7487, and a sixth field added if one outlier is removed from the set (data not presented). The other two fields, however, show considerably less correlation with values of 0.04 and 0.26 bringing the total for all fields combined down to 0.47 (figure 2b). In months with little discharge, even when

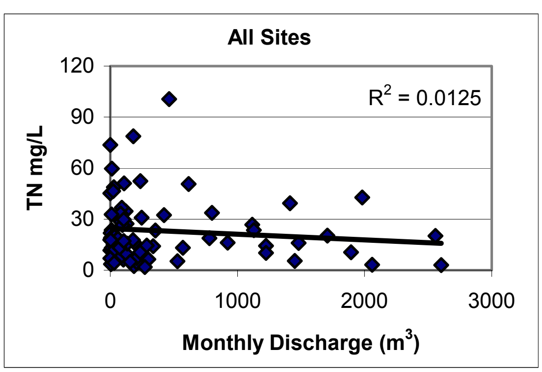

Figure 2a.

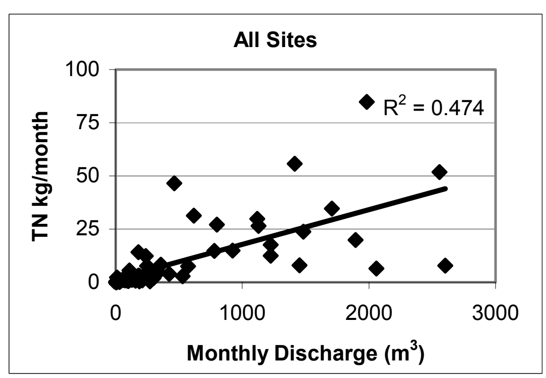

Figure 2b.

concentrations are high, loading is also minimal. As discharge increases the loading becomes less predictable, thus increasing scatter.

Estimated Groundwater Loading from Agriculture

What cannot be seen by monitoring discharge from the fields is the concentration and loading of nitrogen to shallow groundwater. The region is characterized by aquifers separated by layers of clay. The deep aquifers are used for municipal water sources, but the shallow aquifer is of poor water quality and is not pumped. Recharge to the shallow aquifer is by infiltration from irrigation and precipitation on agricultural and municipal lands (Hibbs, 2000).

Much of the area that is currently used for agriculture is on land that sits 20 to 50 meters above the water table (figure 3). With an estimated soil water content of 0.25, a leaching fraction of 25% of applied water (80 centimeters per year for strawberries), and an additional 25 cm/yr storm water infiltration, based on equation 4 water applied to the fields can take from 10 to 30 years to reach groundwater depending on the depth to groundwater at a particular site and the leaching rate. When a leaching fraction of 15% is used, the time to groundwater increases to 15 to 35 years for the same range in depth.

Current fertilization practices used by strawberry growers in the watershed include the use of controlled release fertilizer, at a rate of approximately 196 (Olsen, et al, 2000) to 224 (UC IPM, 1994) kg N/ha, banded into the planting beds prior to planting. The 2001 Orange County Crop Report stated 41,232 metric tons of strawberries were

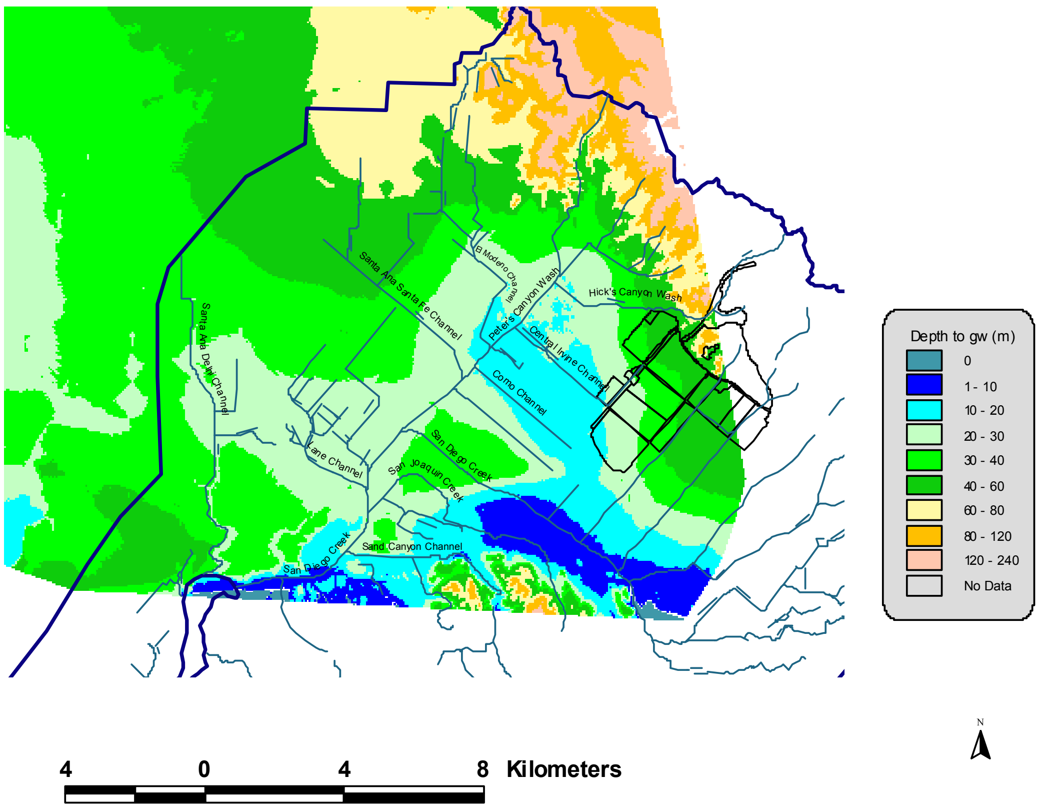

Figure 3. Depth to groundwater.

produced countywide. Of that total, the San Diego Creek watershed produced an estimated 90% (SCREC, 2002) on 431 ha (OC PFRD, 2001b). With nitrogen making up approximately 0.113% of the fresh fruit weight (Albregts and Howard, 1978), total fruit N content is 41,730 kg. Because nitrogen recovered in vegetative plant material roughly equals that in fruit (Archbold and MacKown, 1988; Langford, 1996), doubling that amount to account for plant uptake yields a total crop uptake of 83,460 kg.

At a fertilization rate of 196 kg/ha N, on 431 ha, and an estimated 385 kg N lost to N_2O, equations 2 and 3 yield 7,010 kg, or 7%, of applied nitrogen leaching past the root zone. When combined with roughly 37 to 45 cm of water per ha (a range of 15-25% of irrigation requirement plus 25 cm storm water infiltration) leaching past the root zone, equation 5 calculates an average concentration of nitrogen entering groundwater at just over 4 mg/L (or 20 mg/L as nitrate) at a leaching rate of 15%, or just under 4 mg/L (16 mg/L nitrate) at a leaching rate of 25%.

At a fertilization rate of 224 kg/ha N, for the same land area, estimated N lost to N_2O increases to 450 kg, and equations 2 and 3 yield 19,030 kg for 17% of applied nitrogen leaching past the root zone. When the nitrogen leaching value is combined with storm water infiltration and 15-25% of irrigation requirement leaching past the root zone, equation 5 gives the concentration of nitrogen to reach groundwater at 12 mg/L (or 53 mg/L as nitrate) at a leaching rate of 15%, or 10 mg/L (44 mg/L nitrate) at a leaching rate of 25%.

Once in the groundwater, the nitrate then travels along the flow paths of the aquifer toward Peters Canyon Wash, tributary to San Diego Creek (figure 4). Significant contribution of nitrate to surface water has been shown to originate from groundwater sources (Hibbs, 2000). One area in particular that is affected by groundwater mixing with surface water is along Como Channel. This channel lies along the gradient between the lower portion of the remaining agriculture region and Peters Canyon. Studies along the channel have found nitrate-nitrogen concentrations to be in the range of 15 mg/L to 20 mg/L at the confluence with Peters Cyn Wash (Hibbs, 2000; OC PFRD, 2001), while the headwater of the channel has a concentration of less than 1 mg/L (Hibbs, 2000). Between the headwater and confluence are inflows from weepholes and drains, as well as an outlet from a dewatering facility where shallow groundwater is pumped and released

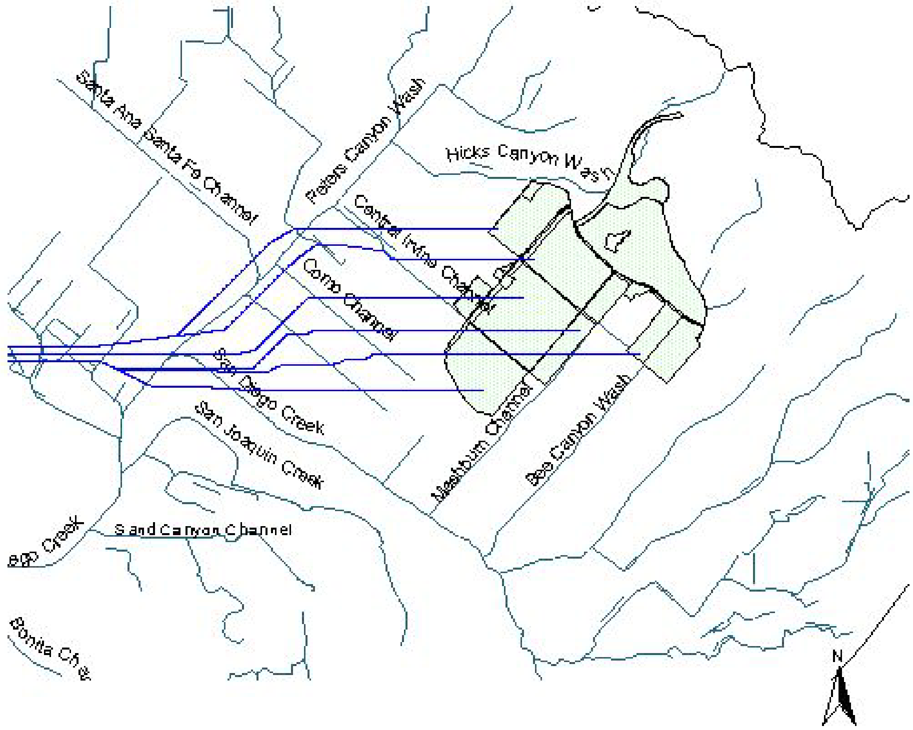

Figure 4. Direction of groundwater flow away from the agricultural area.

into the channel untreated. Along with concentration, the discharge also increases along the channel from 1.7 x 10^{-5} to between 0.01 and 0.02 m^3/s (Hibbs, 2000; OC PFRD, 2001). Here groundwater is playing an important role in surface water quality as it is the primary component of surface water in this channel.

Model Results

In reviewing the data input to the model, initial quantifications can be made regarding the percent of land coverage (figure 5a) and the percent of NO_3-N contribution (figure 5b) by different land use types. Nurseries contribute the greatest per unit nitrate load with only one percent of land area, but twelve percent NO_3-N contribution. Agriculture also shows a greater percentage of nitrate contribution than land use with values of eight and two percent, respectively. Open space areas reverse this trend accounting for 28% of land, but only 17% of NO_3-N. Finally, urban areas are closer to even, with 69% land use coverage and 63% nitrate contribution. As the majority of nitrate in the watershed comes from urban areas, it is expected that these areas will have the greatest potential to benefit the watershed from changes in management measures.

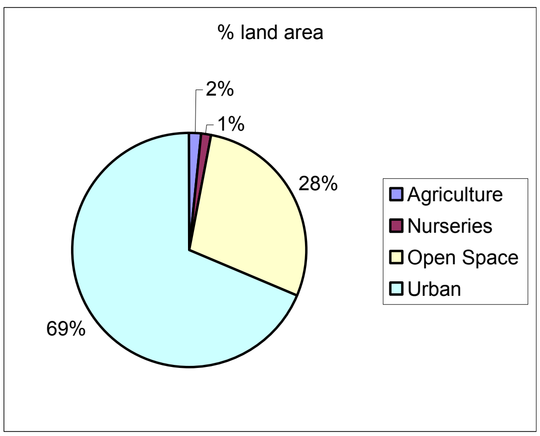

Figure 5a.

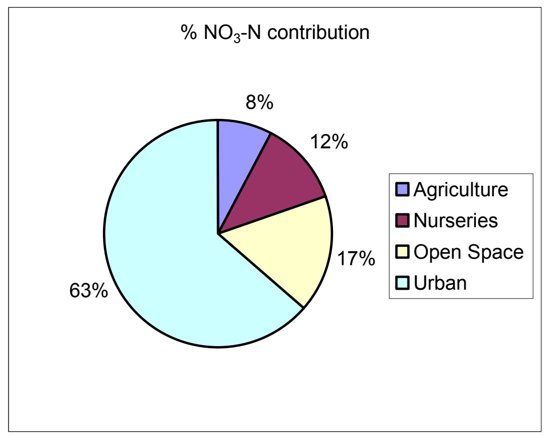

Figure 5b.

The Orange County 2001 Regional Monitoring Program (RMP) report lists an average NO_3-N concentration at San Diego Creek at Campus Drive of 7.89 mg/L for the period of July 1, 2000 through June 30, 2001. The model, which uses measured or estimated inputs of nitrate from urban, agricultural, nursery, and open space sources, and does not account for any loss through the system, reaches a steady state concentration of 10.29 mg/L.

If management changes in all areas could produce a 50% reduction in nitrate contributions, the final concentration of 5.14 would not be reached for just over forty years due to the time lag from agricultural and nursery groundwater contributions. The greatest change, however, would be seen immediately as a result of changing surface water concentrations. A comparison of the results seen from changing all sources versus focusing efforts to change on only one sector while leaving the others constant is shown in figure 6.

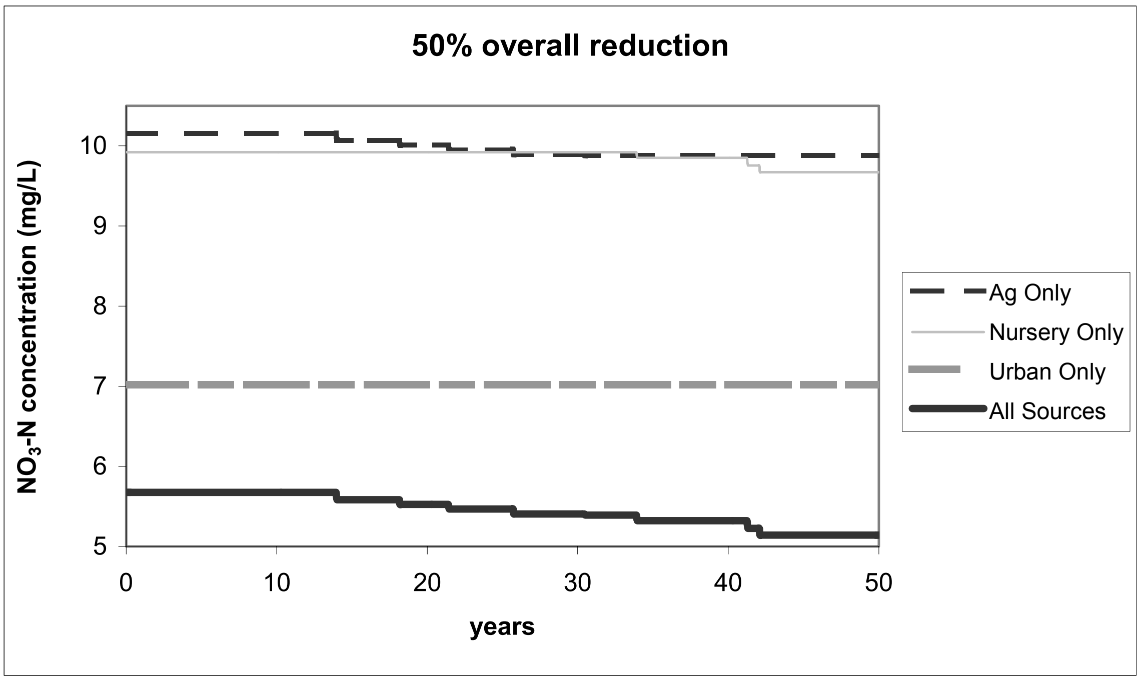

Figure 6. Comparison of a 50% reduction to all sources (agriculture, nursery, urban, and open space) versus comparable reductions to individual sources.

Looking at the effects of management changes on the various inputs paints the following picture:

- Reduction in NO_3-N export from urban areas yields the single greatest change in total concentration.
- Urban contributions in this model are received only through surface water, thus the effects of changes are seen immediately.

- Because nursery and agriculture operations affect shallow groundwater contributions as well as surface water, effects of change will not be fully realized for upwards of 30 years.

A 10% reduction in urban nitrate contributions, with no change to other areas, will yield a final NO_3-N concentration of 9.63 mg/L; a greater overall effect than a 50% reduction to either agriculture or nursery operations, and in less time (figure 7). The final concentration from the 50% reduction to agricultural sources is 9.88 mg/L, but it does not reach that level for 30 years, and remains at 10.16 mg/L for the first fourteen years. Similarly, reductions to nursery sources yields an immediate drop to 9.92 mg/L, but does not reach the final 9.67 mg/L concentration until year 43.

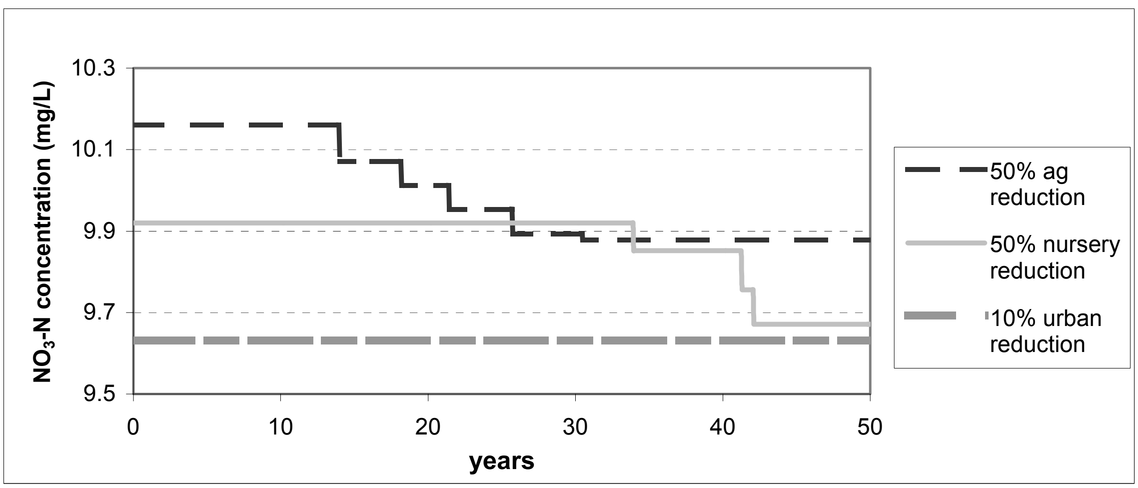

Figure 7. Comparison of a 10% reduction to urban NO_3-N contributions, versus a 50% reduction to either agricultural or nursery sources.

Discussion

Contributions of nitrogen to surface water from agricultural sources are not limited to that from strawberry fields, but strawberries do comprise the majority of crop sites within the watershed. Orchards of avocado and some citrus remain in foothills of the Santa Ana Mountains and Santiago Hills on about 526 ha (OC PFRD, 2001), but much like the strawberries, that area is also decreasing. Any contribution of nitrate to groundwater that may come from these orchards is likely to reach the deeper aquifers and will not be a concern to mixing with surface water. Any runoff from these orchards that flows directly into surface water channels is reflected in the Orange County nutrient study as coming in from Hicks Canyon Wash and/or Peters Canyon Wash upstream of Hicks Canyon Wash. This area is also combined with open hillsides and exposed rock. Tomatoes, grown on 166 ha (OC PFRD, 2001), are drip irrigated throughout the growing season of March to November (SCREC, personal communication, 2003), and receive approximately 180 kg/ha N fertilizer (SCREC, personal communication, 2003; UC IPM 1998). Extrapolated contribution estimates from strawberry fields to surface and ground waters likely overestimate actual contributions from tomato crops. Growing conditions of the remaining miscellaneous crops, grown on approximately 160 ha (OC PFRD, 2001), were not included in this study, but are not considered likely to contribute nitrate to either surface or ground waters at levels that are significantly greater than those calculated from strawberry fields. Nurseries cover just over 405 ha in the watershed, but are included in a separate category in the TMDL, so contributions from these areas, are considered as a distinct land use type.

Estimates of nitrate contributions from strawberry crops to surface water were based on actual measurements of flow and concentration and averaged and/or extrapolated to the desired time span. Uptake of nitrate by algae or other plants growing in the channels was not considered. Calculations of leaching rates are based on published accounts of irrigation and fertilization requirements rather than reports from growers on actual rates. These calculations take into consideration uptake by the plants, as determined from reported production values and published nitrogen content of strawberries, estimated denitrification of controlled release fertilizer, and surface runoff. Actual leaching rates and concentrations will vary based on individual grower practices.

During a study period covering 1999 through early 2000, Hibbs found the only source of nitrate to surface water more important than groundwater was runoff from commercial nurseries (Hibbs, 2000). The third most important source was urban runoff. Specifically not on the list of important or significant sources of nutrients to surface water was non-nursery agriculture. These conclusions are supported by the model estimates. If groundwater contribution is taken as a whole, rather than as components of various land use contributions, the model estimates 10% of nitrate reaching the final monitoring station to be from groundwater sources. Conversely, if only surface water inputs are considered, the percent contribution from agriculture drops from 8% to 2%, while nursery contribution drops from 12% to 7%.

A likely cause of the current high nitrate concentrations in shallow groundwater is the historical land use of citrus production in the watershed. In the early 1980s the upper part of the watershed (above San Diego Creek at Campus) consisted of roughly 8,500 ha of agriculture and 11,330 ha of urban development. By 1999, agriculture was down to 5,260 ha and urban areas up to 14,370 ha. Open space remained relatively constant over this time period around 30% of land area or 8,500 ha (Tetra Tech, 2000). This trend of decreasing agricultural area and increasing urban development has continued through 2002.

Each year the area of row crops in the watershed decreases as land is developed for urban uses. As a result, there may be an immediate shift toward increased contributions of nutrients to surface waters as urban landscapes, often irrigated with high nutrient recycled wastewater, increase in area. Reclaimed water in the Irvine Ranch Water District area has an average nitrate-nitrogen concentration that varies from 4.5 to 7.9 to 13.8 mg/L depending on the site from which it is delivered (IRWD, 2001). Although over 405 ha of agricultural land are currently irrigated with recycled water (IRWD, 2001), little irrigation water outside the plant establishment period actually runs off the fields. The long term effect of land use change, however, will have more to do with landscape management and its eventual effect on groundwater nitrate concentrations.

Although the TMDL does not address limitations of nutrients to groundwater, either from agricultural or urban sources, evidence of groundwater mixing with surface water provides the need to investigate what contributions exist. Estimates using the 25% irrigation leaching rate, indicate that strawberry fields may be leaching nitrate at concentrations ranging from 4 to 10 mg/L as N for 431 ha of production depending on fertilizer application rate. If it is assumed that 75% of growers use the higher rate of 224 kg/ha and only 25% use the lower rate of 196 kg/ha, the resulting average concentration is 8.25 mg/L. However, if those numbers are reversed, with a majority of growers using the lower fertilization rate, the concentration drops to 5.16 mg/L. Current measurements of nitrate-nitrogen concentrations in the groundwater are upward of 14 mg/L. Because travel time from the surface to groundwater varies from 10 to 30 years depending on location within the main agricultural area, effects of any changes in concentration from surface leaching will not be reflected immediately and mixing will continue to occur at the higher concentration. Consideration for this time lag needs to be made when evaluating the progress of TMDL limitations on surface water sources.

The model is intended not to provide a complex accounting of all sources and interactions of nitrate through the watershed, but rather to illustrate the relative differences in reactions from various sources. Because nitrate-N contributions are summed without consideration for loss within the system, the model overestimates the concentration observed at the final monitoring point, SDMF05. Estimations of annual nitrate concentration at nine of fifteen sites, based on limited summer season data, may also have contributed to an elevated final concentration. Flow data, although estimated at eleven sites, matched well with observed flows at both BARSED and SDMF05, and is not thought to be a significant source of error.

Groundwater flows into the system were set to equal current inputs from agricultural and nursery sources. It is possible that a greater contribution of groundwater than accounted for could be masquerading as 'urban' flows and thus would not show the same immediate response to management measures as 'true' urban surface flows. Regardless of this potential overstatement, urban areas remain the majority contributors of nitrate to the system and show the quickest response to change.

Conclusions

The nutrient TMDL established for the Newport Bay/San Diego Creek watershed outlines the timeline for reduction in loading allocations for various point and non point sources. Agricultural discharges are targeted for summer season (April – Sept.) reductions to be achieved not later than 2002 for an initial limitation of approximately 10,400 kg, followed by further limitation for 2007 at 5,200 kg. Monitoring of eight field sites by the SCREC indicates that both the 2002 and 2007 goals have already been obtained, due in part to the decrease in agricultural area within the watershed since the TMDL was written in 1998. Nutrient contributions from agricultural sites are likely to become even less important over the coming years as currently remaining agricultural lands shift to urban uses. Groundwater contribution of nitrate to the surface water will continue to be an important factor for years to come as the effects of land use practices from thirty years ago are just now being felt.

Although nurseries contribute the greatest amount of nitrate per unit of land, the majority of nitrate in the watershed appears to originate from urban sources. Further studies in urban areas, such as the in-progress IRWD residential runoff study and others in recreational, commercial, and industrial regions, are needed to more specifically identify urban sources. Once these have been identified, appropriate management measures can be implemented to stem the flow of nitrogen to Newport Bay.

Additional studies on urban leaching rates may also be useful. As long standing agriculture land is replaced by urban development, previously leached N remains within the unsaturated zone. Any nitrogen already in the groundwater will reach the river, but the fate of the unsaturated zone N will depend on the subsequent drainage in the zone. The leaching rates of water and fertilizers from suburban lawns, parks, and/or other landscaped areas in the watershed are not clear, but they play an important role in the rate of continued groundwater N contribution to surface water.

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